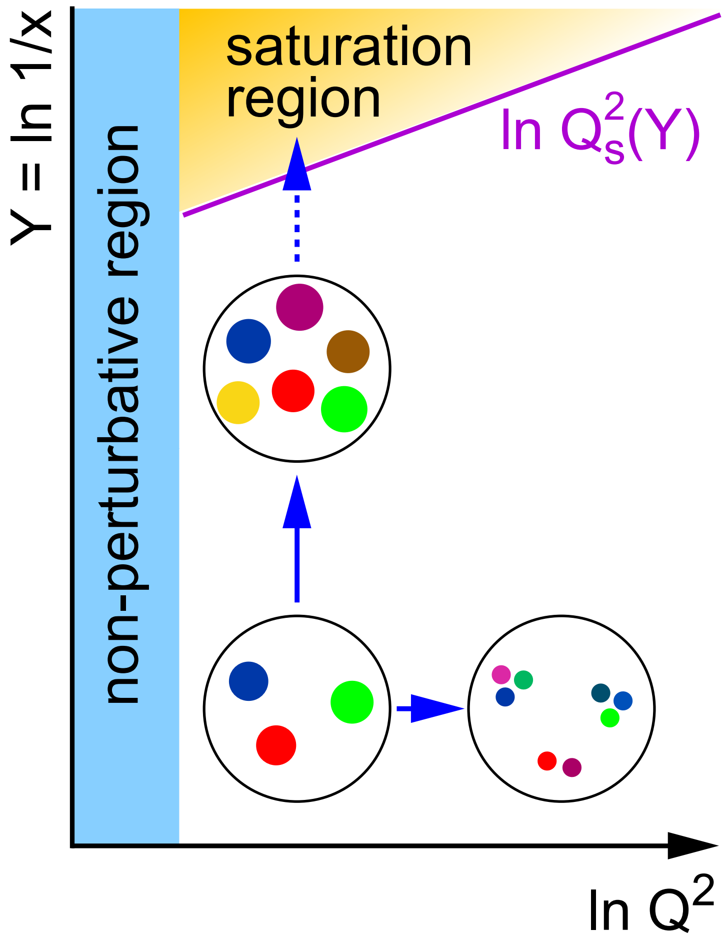

The EIC, Saturation, and the CGC

Thomas Ullrich (BNL)

RIKEN Glasma Workshop, BNL

Wednesday, May 12, 2010

BROOKHAVEN NATIONAL LABORATORY

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EIC Science Case

How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

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How do we understand the visible matter in our universe in terms of the fundamental quarks and gluons of QCD?

- What is the nature and role of gluons and their self-interactions (eA, ep)
  - Study the Physics of Strong Color Fields
    - Establish (or not) the existence of the saturation regime
    - Explore non-linear QCD
    - Measure momentum & space-time distributions of glue
  - Study the nature of color singlet excitations (Pomerons)
  - Test and study the limits of universality (eA vs. pA)

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- What is the nature and role of gluons and their self-interactions (eA, ep)
- What is the internal landscape of the nucleons
  - What is the nature of the spin of the proton?
    - $\Delta G(Q^2, x)$, polarization of the sea quarks
    - Transverse spin and momentum measurements and correlations
  - What is the Three-Dimensional Spatial Landscape of Nucleons?
    - Transverse imaging of quarks and gluons in nucleons
    - Transverse momentum dependent measurements and correlations

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- What is the nature and role of gluons and their self-interactions (eA, ep)
- What is the internal landscape of the nucleons
- What governs the transition of quarks and gluons into pions and nucleons?
  - How do fast probes interact with the gluonic medium?
    - Energy loss of quarks and gluons
  - Mechanism of fragmentation?

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- What is the internal landscape of the nucleons
- What governs the transition of quarks and gluons into pions and nucleons?
- Electroweak Physics (studies underway)
  - Parity Violating deep inelastic scattering (PVDIS)
    - Quark helicity distributions
    - Isovector EMC effect
    - Potential ultraprecise weak mixing angle measurements
  - Lepton Flavor and Number Violation
    - Electron-tau lepton conversion

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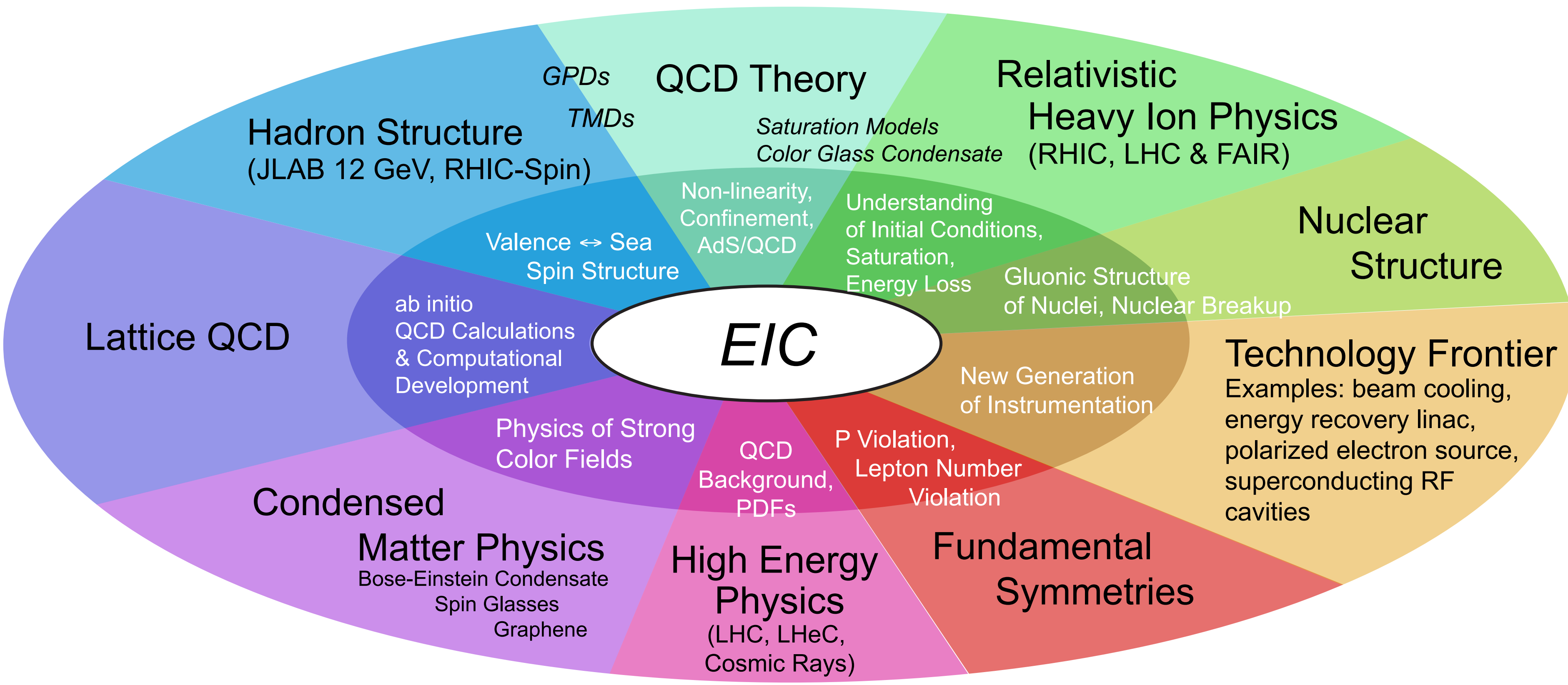
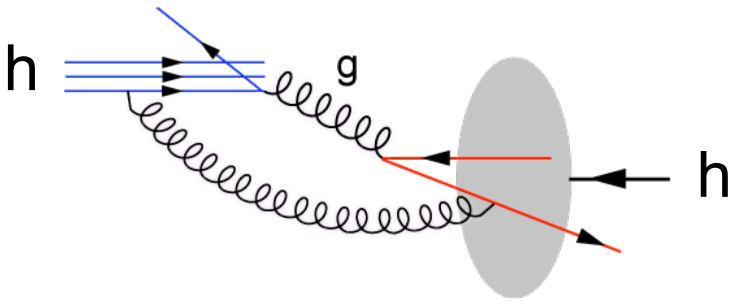
The machine presents a unique opportunity for fundamental physics:



Why Electrons ?

Hadron-Hadron



- Test QCD
- Probe/Target interaction directly via gluons
- Lacks the direct access to parton kinematics
- Probe has complex structure

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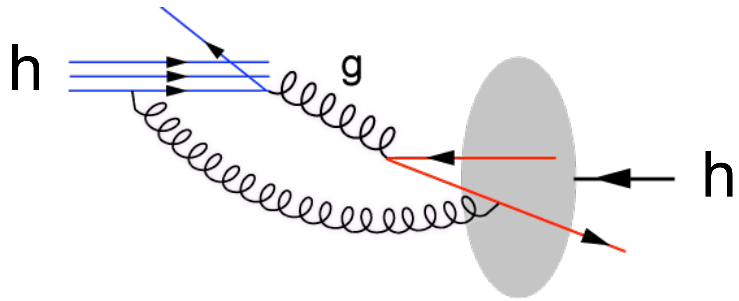

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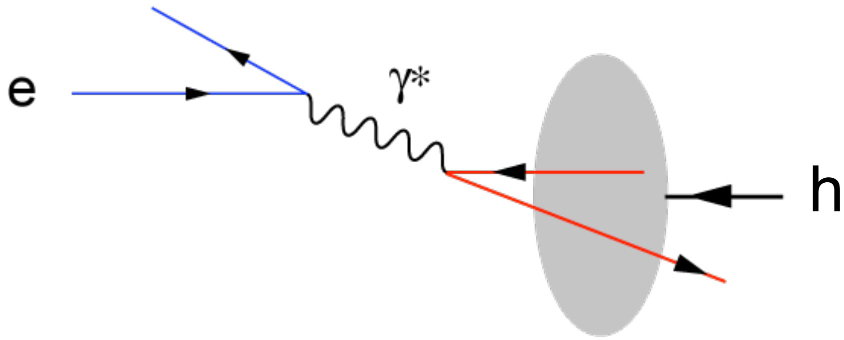
Electron-Hadron (DIS)



- Explore QCD & Hadron Structure
- Indirect access to glue
- High precision & access to partonic kinematics
- Probes partons w/o disturbing them or interfering with their dynamics

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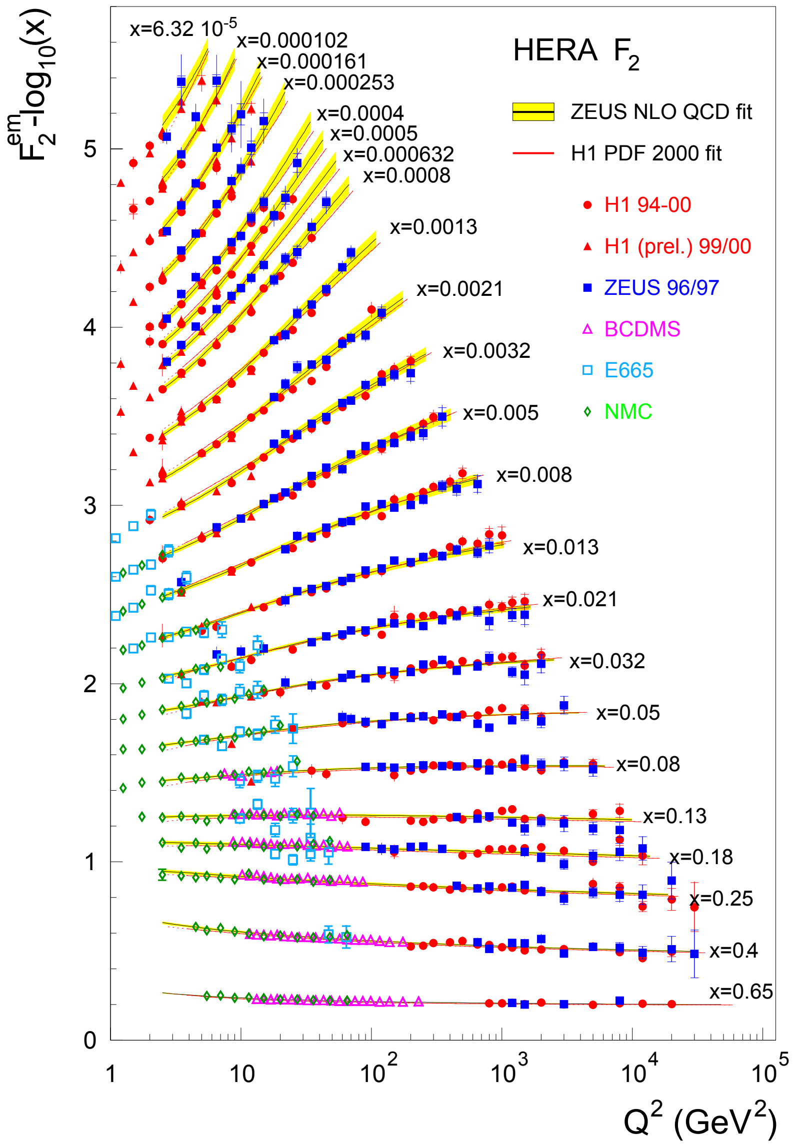

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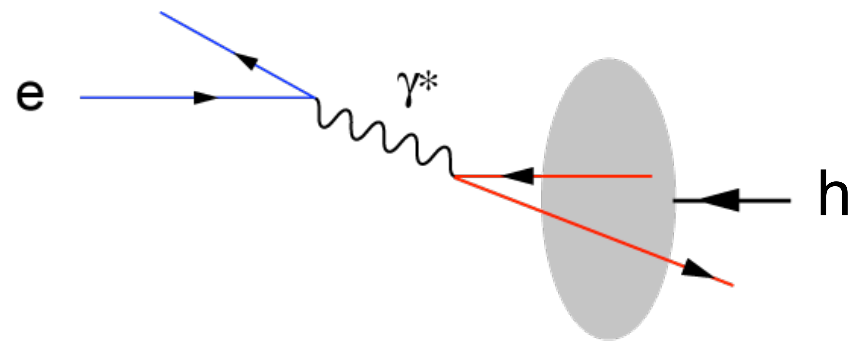

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- Indirect access to glue
- High precision & access to partonic kinematics
- Probes partons w/o disturbing them or interfering with their dynamics

Both are complementary but for precision ⇒ ep, eA

Gluon Distributions and Saturation

How to probe saturation? $G(x,Q^2)$ is not an observable!

Measurement
$\sigma(x, Q^2, A, t, W, \ldots)$

Structure Function F_2,
$\delta F_2/\delta \ln Q^2$, F_L, F_2^D, F_L^D,
Dipole $d\sigma/db$, ...

Linear QCD Models
(DGLAP, BFKL)

Non-Linear QCD
Higher Twist,
saturation models,
CGC

$\Longleftrightarrow$
comparison

$G(x,Q^2)$

model
dependent

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$G(x,Q^2)$

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dependent

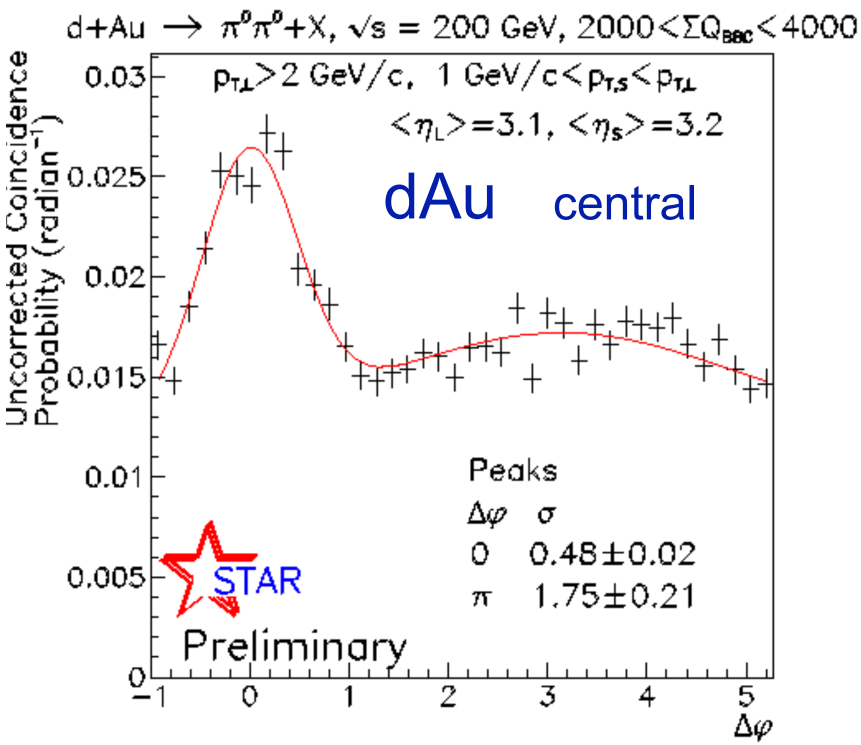
Comparison (to constrain/reject models) requires

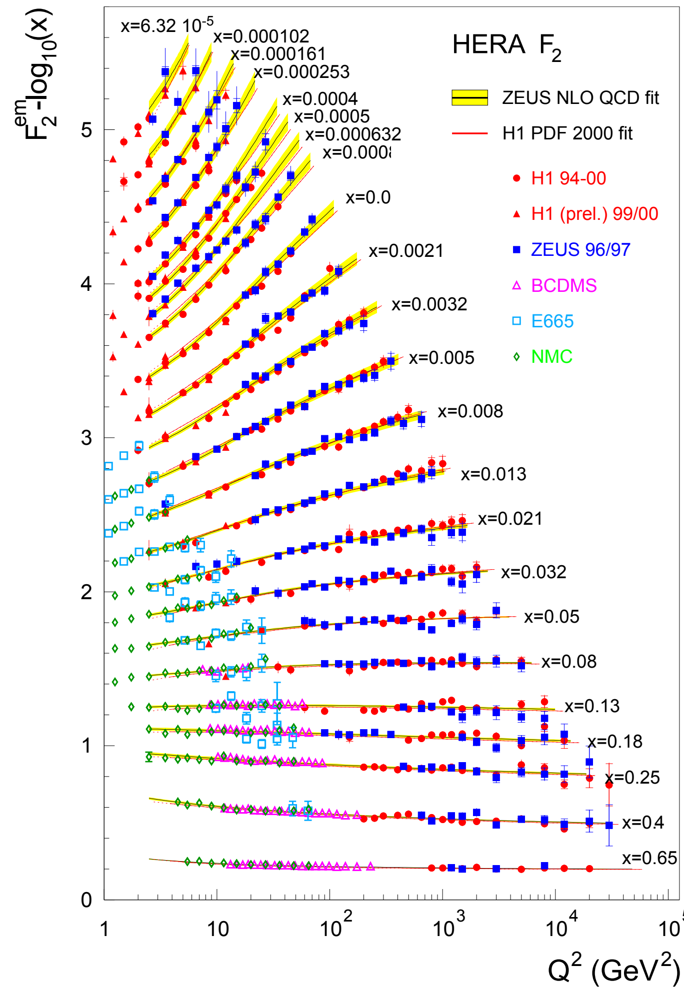
- "lever arm" in x, Q^2, A, ...
- complementary measurements (incl., semi-incl., excl., jets, DIS & diffractive, varying probes, ...)

EIC - Reaching the Saturation Regime

Saturation:

- Au: Strong hints from RHIC at $x \sim 10^{-3}$
- p: No (?) hints at Hera up to $x=6.32 \cdot 10^{-5}$, Q^2 = 1-5 GeV^2





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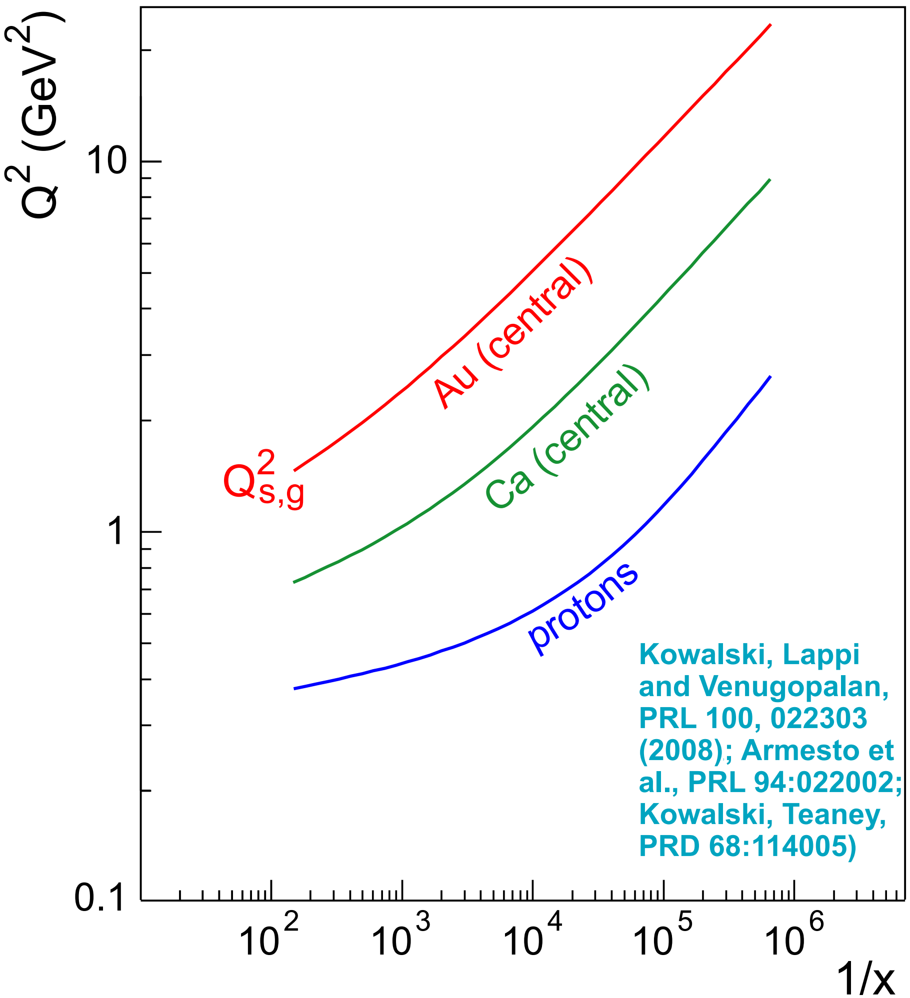

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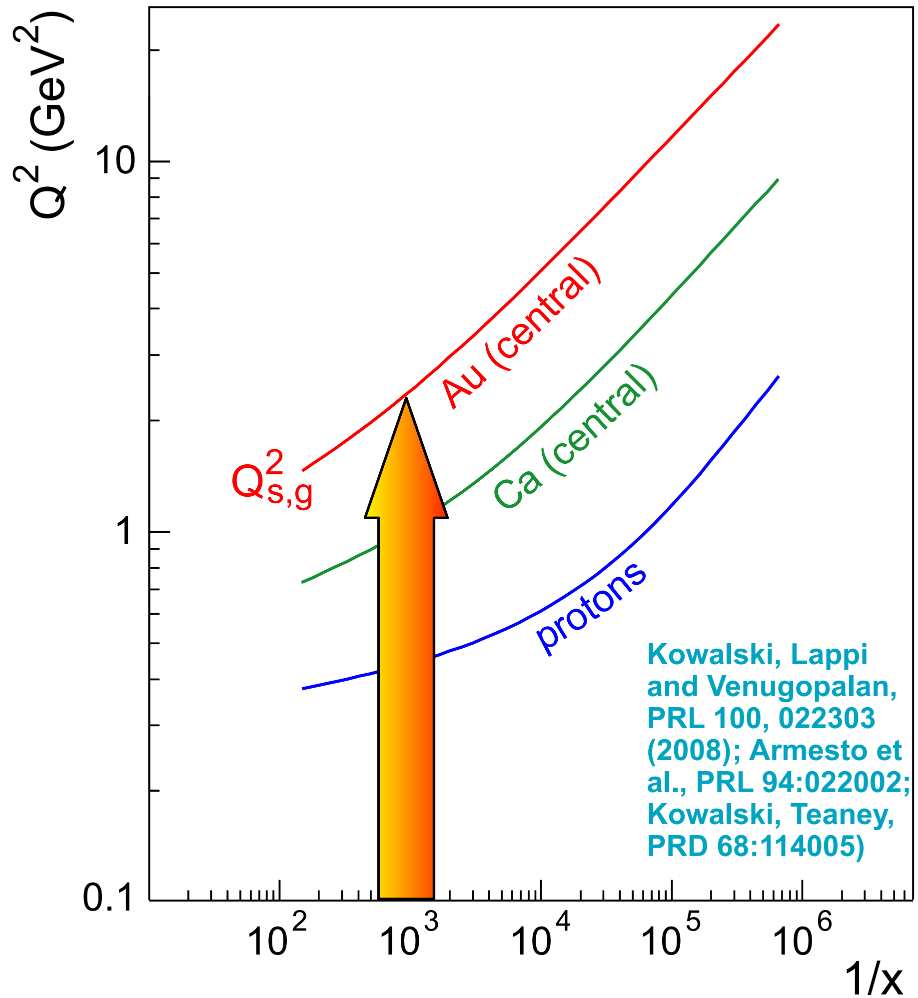

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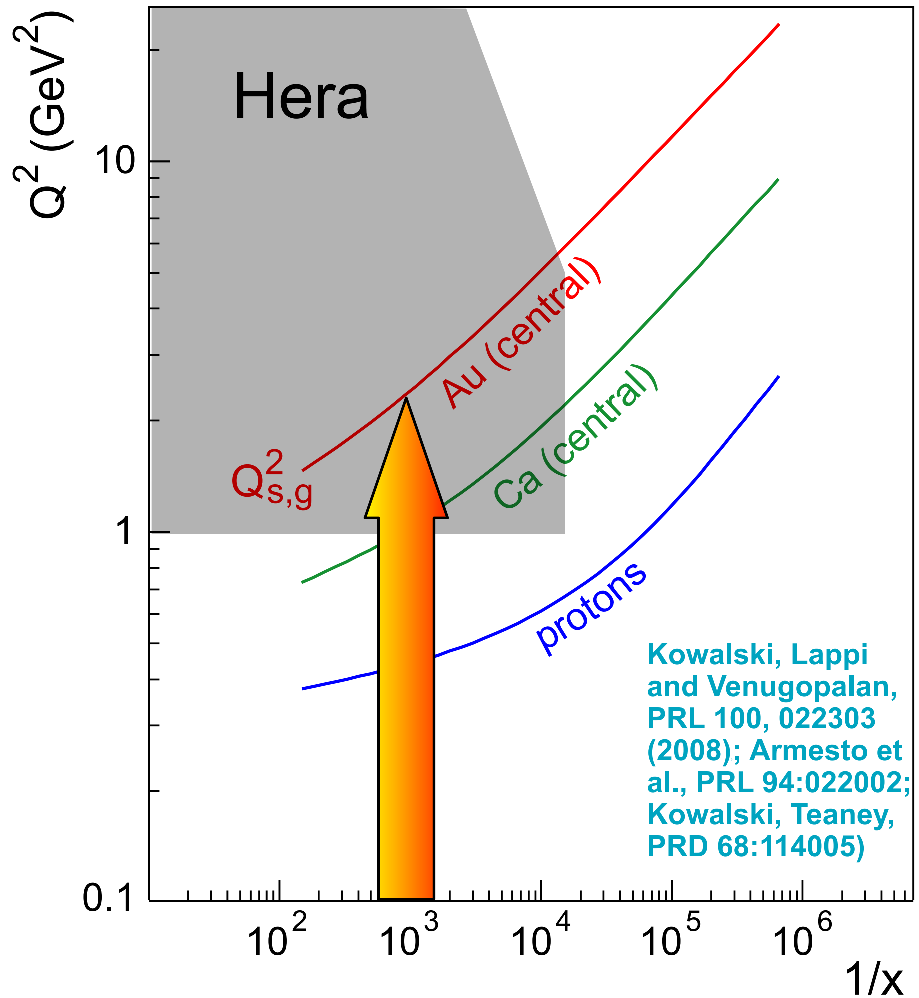

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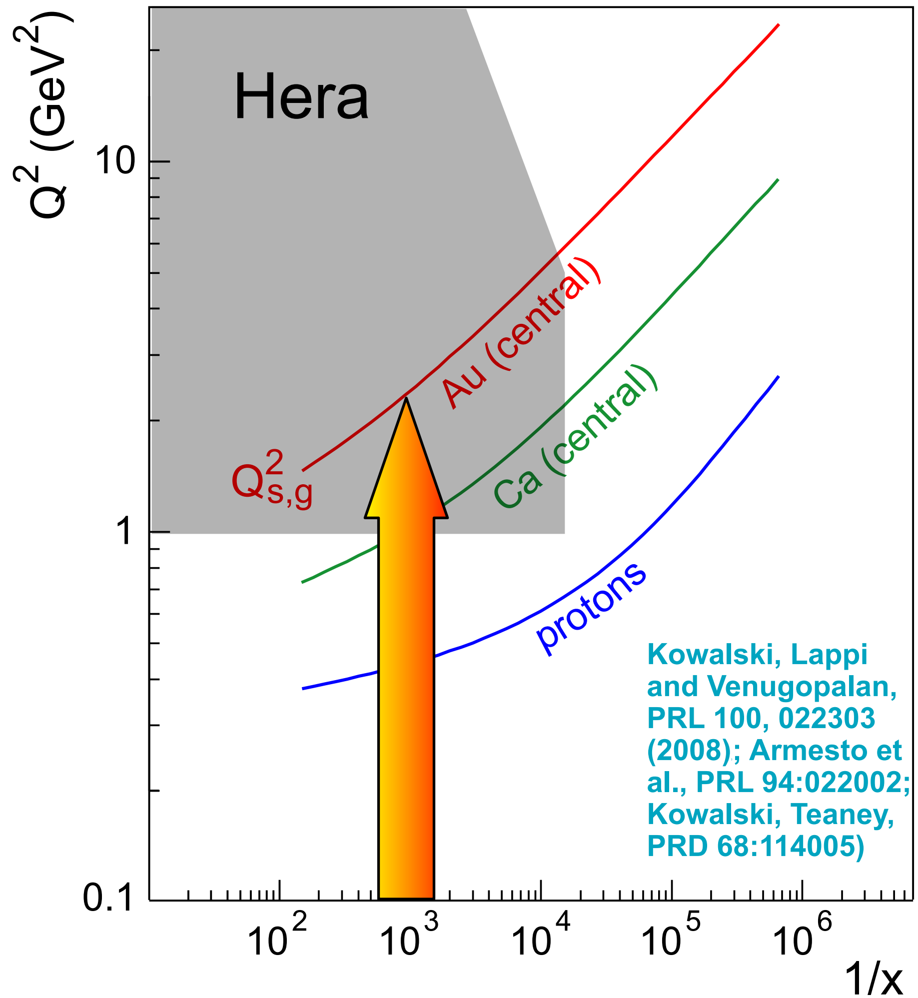
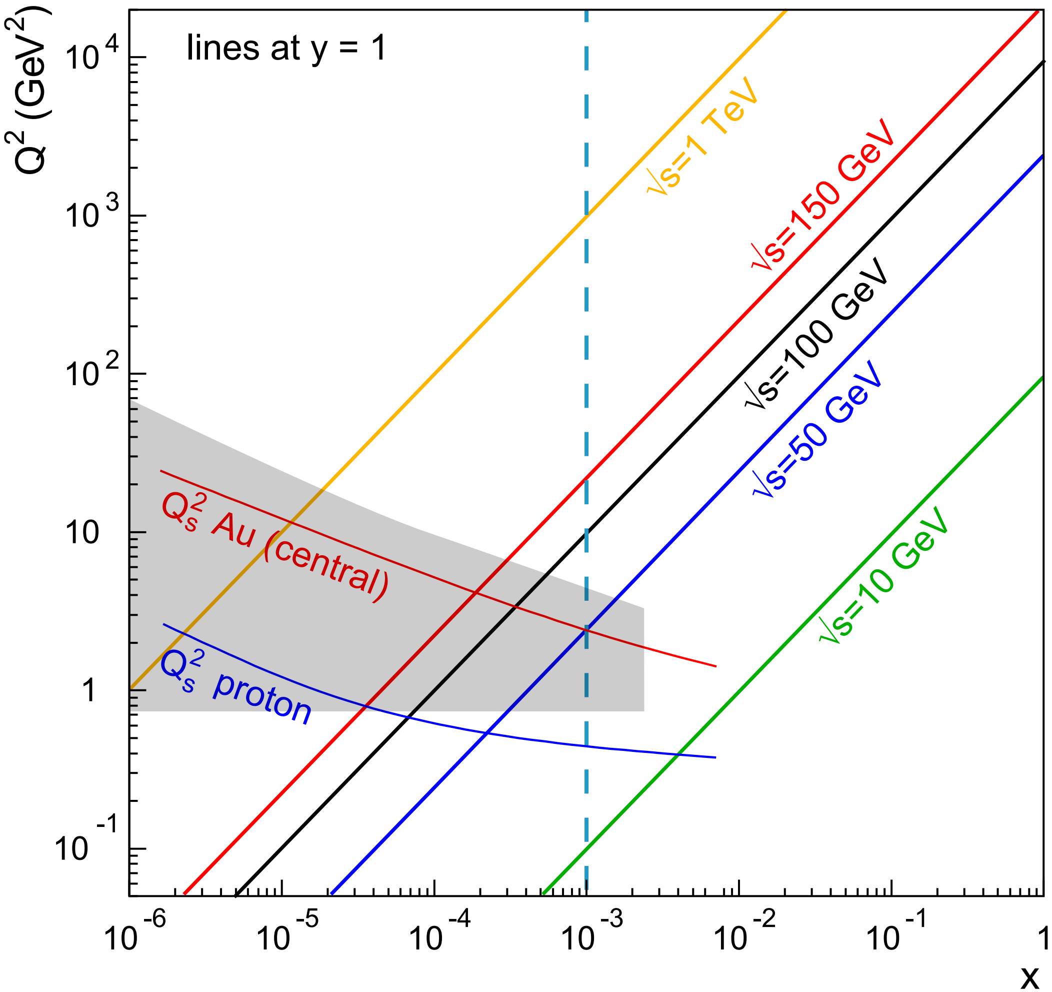
Finding RHIC and Hera & Q_s scalings consistent



EIC - Energy Requirements

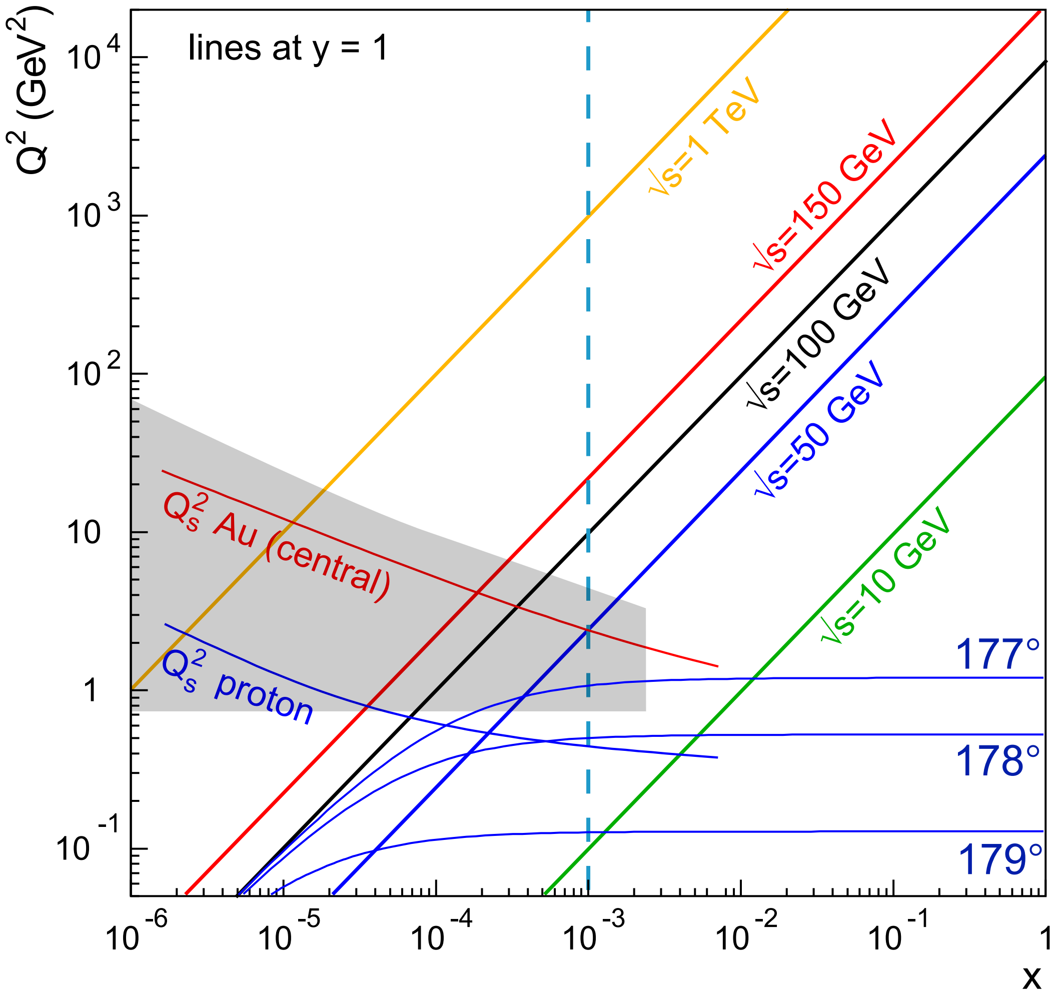


Coverage

- Need lever arm in Q^2 at fixed *x* to constrain models
- Need $Q > Q_s$ to study onset of saturation
- $Q^2 = 4EE'\sin^2\theta/2$
  - hard to get much lower than 0.5-1 GeV^2

- ep: ~ 1 TeV is needed
- eA: $\sqrt{s}$ = 50 GeV is marginal, around $\sqrt{s}$ = 100 GeV desirable

EIC - Energy Requirements



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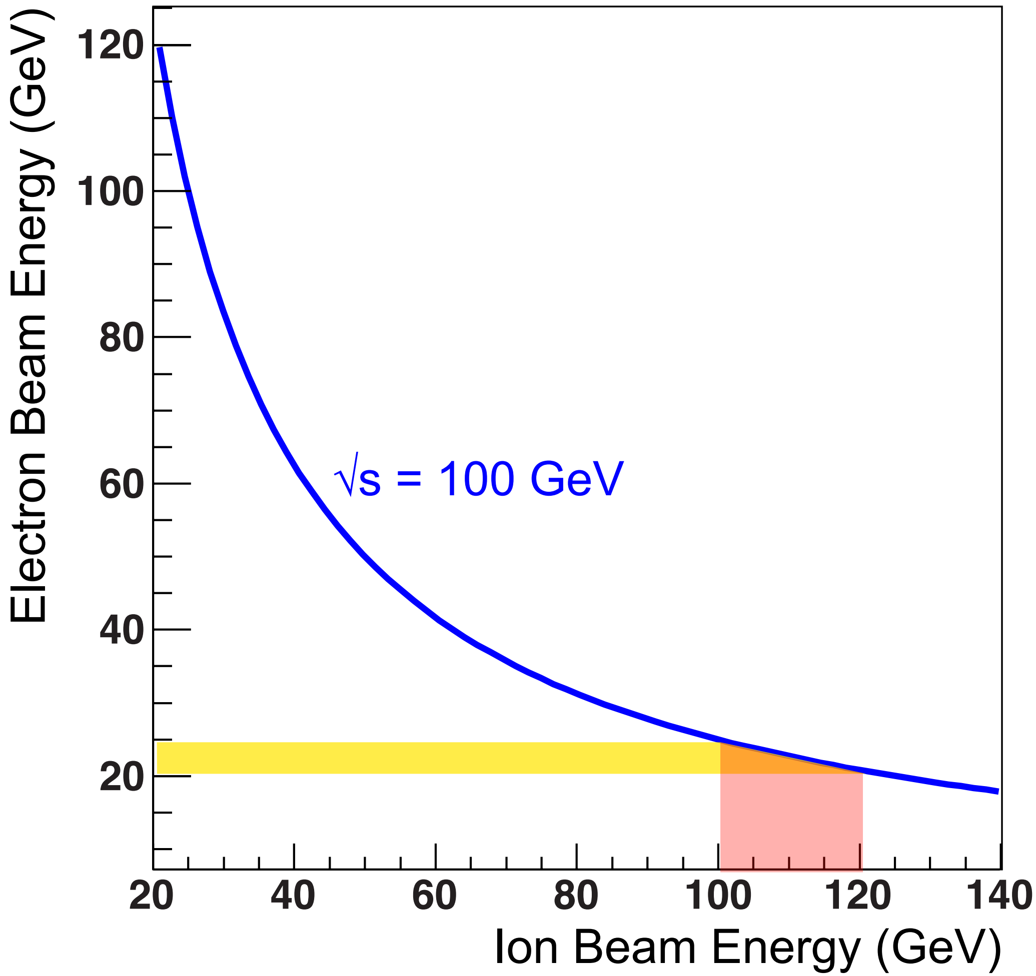

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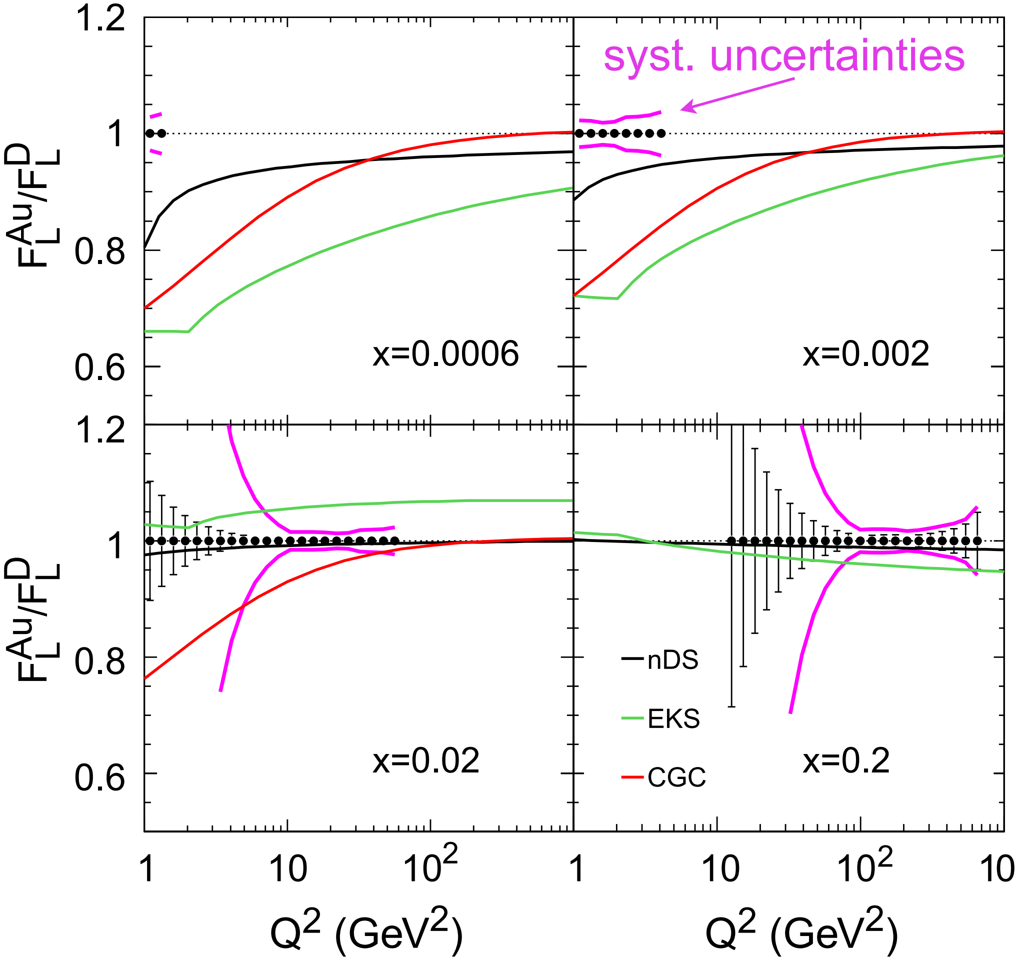
Current best estimate to study saturation:

Electron energy ~ 20 GeV x Ion Energy ~ 100 GeV

EIC - What Luminosity is Needed?

Hera suffered from low luminosity: $L = 1.6\text{-}3.8\cdot10^{31}\ \mathrm{cm^{-2}\ s^{-1}}$

EIC-Example F_L: *inclusive* measurements at different $\sqrt{s}$, assume 1% energy-to-energy normalization



$\int \mathcal{L}dt$ = 4/A fb^{-1} (10+100) GeV &
4/A fb^{-1} (10+50) GeV &
2/A fb^{-1} (5+50) GeV

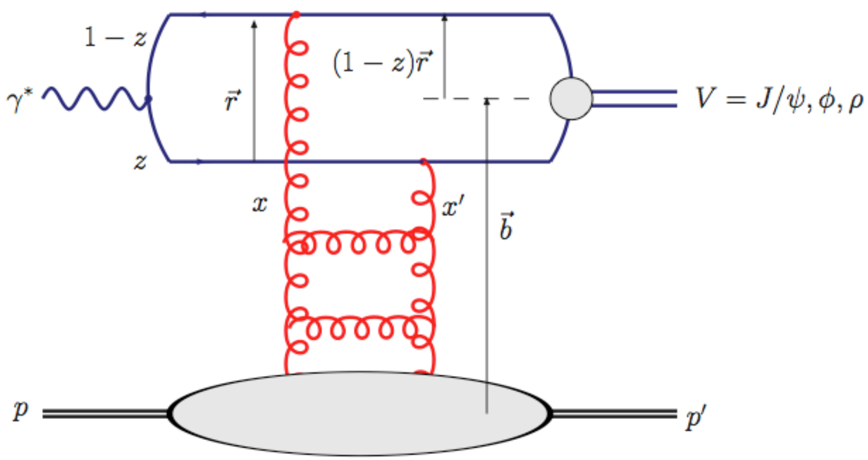
All together 10 weeks at $L \sim 4\cdot10^{33}\ \mathrm{cm^{-2}\ s^{-1}}$ and 50% duty cycle
(Note: 100x Hera L)

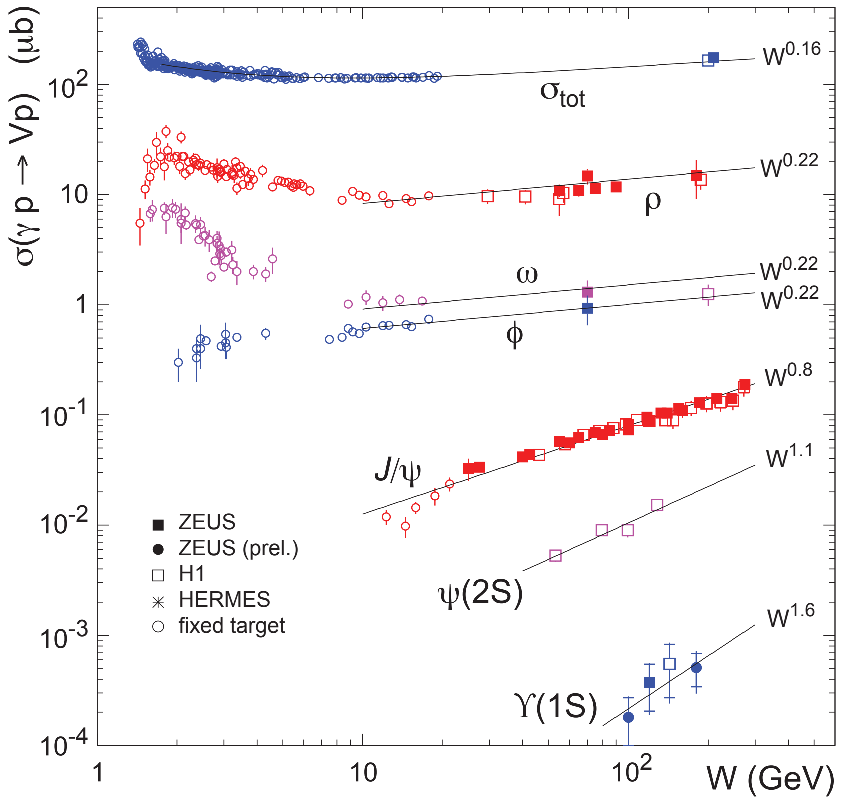
Conclusion from this study:

- Dominated by sys. uncertainties
- More statistics does not provide higher accuracy

EIC - What Luminosity is Needed?

Key measurement: exclusive diffractive vector meson production: e A → e' A' V





Sensitive means to probe $G(x,Q^2)$ and saturation: $\sigma \propto G(x,Q^2)^2$

$\sigma(x_{IP}, x, Q^2, t)$ double/triple differential & small σ

⇒ high L required (statistical >> systematic errors),

(DVCS even more L hungry → GPDs)

EIC - Requirements

Requirements depend on specific measurements

Measurement		√s	L ($cm^{-2}\ s^{-1}$)
Saturation (eA)	Inclusive F2, FL	High √s > 50 GeV preferred √s ~ 100 GeV	moderate ~ 10^{32}
	Diffractive VM & n-differential		high ≳ 10^{33}
3D Imaging (ep and eA)	GPD, TMD n-differential	Moderate √s > 50 GeV	high ~ 10^{34}
Electroweak (ep)	PVDIS, W production, γ−Z interference, Lepton number violation	Moderate to high	very high ≳ 10^{34}
Spin structure of the nucleon (ep)	Inclusive: structure functions, g1, ... Semi-inclusive (tag quark)	High √s > 50 GeV preferred √s ~ 100 GeV	moderate-high ~ 10^{33}
Fragmentation, Energy loss (ep, eA)	Spectra: ν,p_T, Q^2 flavor dependence (c, b)	Low - High √s > 50 GeV (heavy flavor)	moderate ~ 10^{32}

EIC - Realization

High $\sqrt{s}$, high L machine: costs too high to build in one step $\Rightarrow$ staged approach

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  - eRHIC (RHIC/BNL)
  - ELIC (CEBAF/JLAB)

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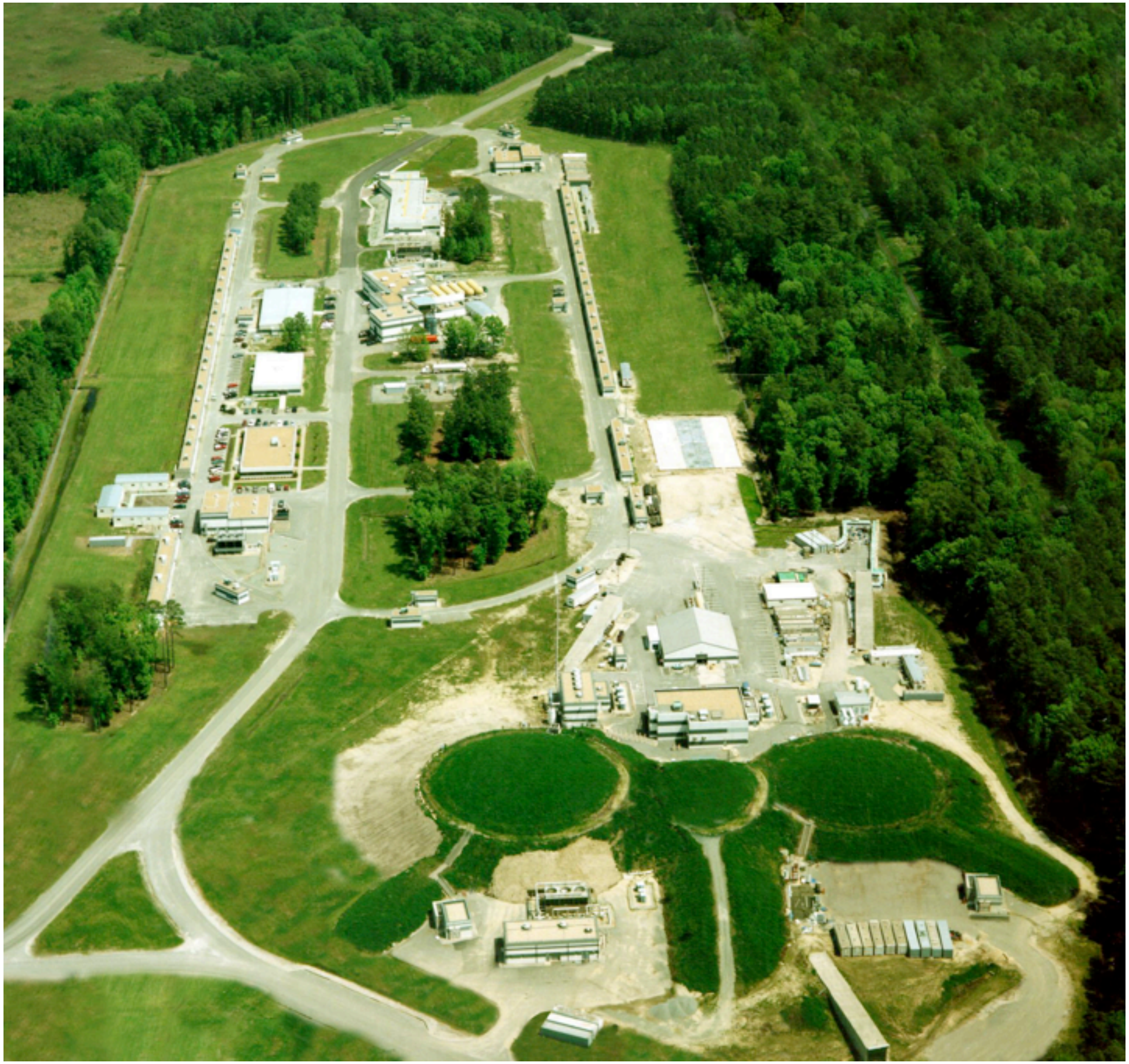
  - eRHIC (RHIC/BNL)
  - ELIC (CEBAF/JLAB)
- Timeline: ~2020 (vital: NSAC Long Range Plan 2012/13)

EIC Concept: CEBAF → ELIC @ JLAB



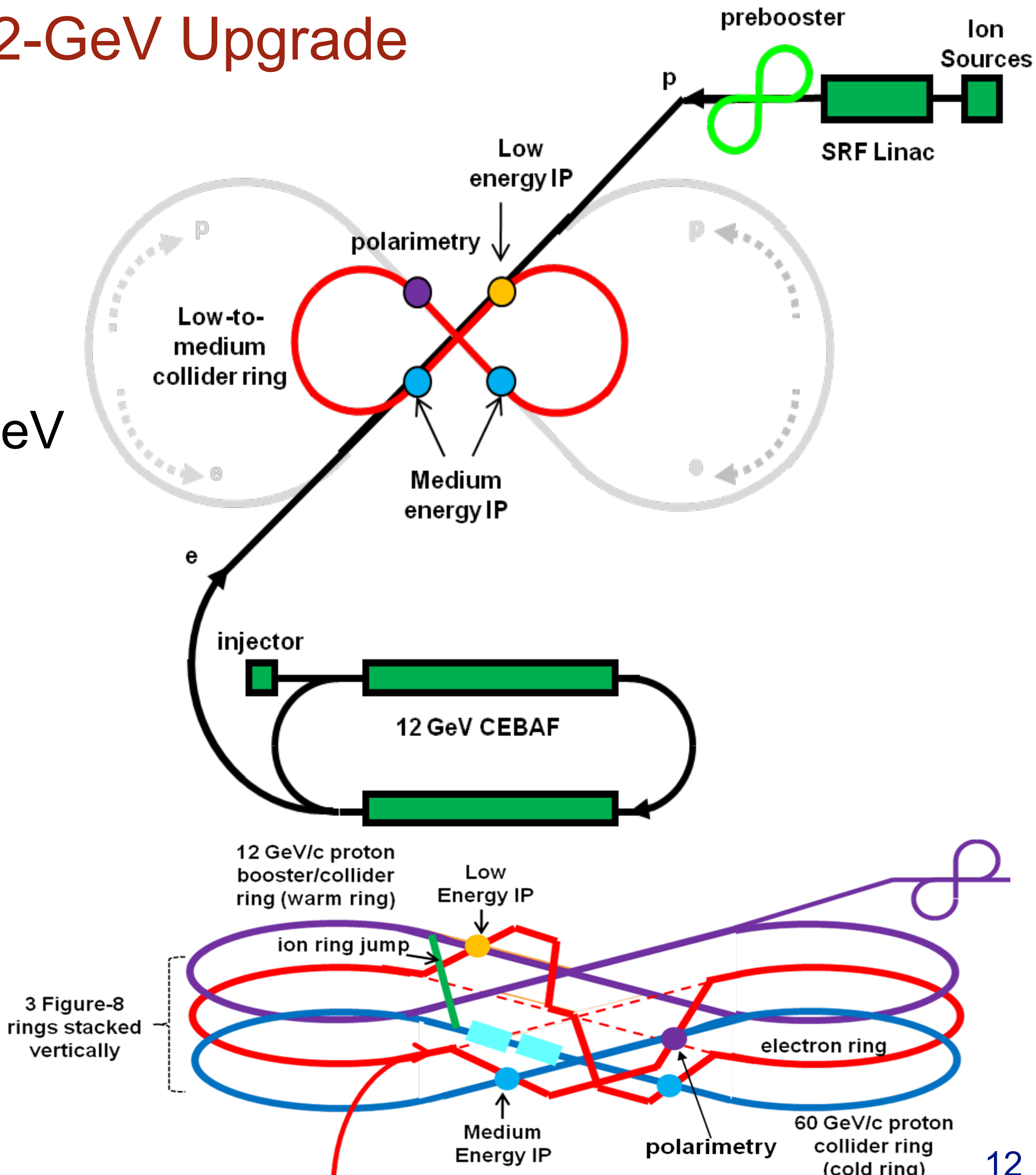
EIC Concept: CEBAF → ELIC @ JLAB

Use CEBAF "as-is" after 12-GeV Upgrade

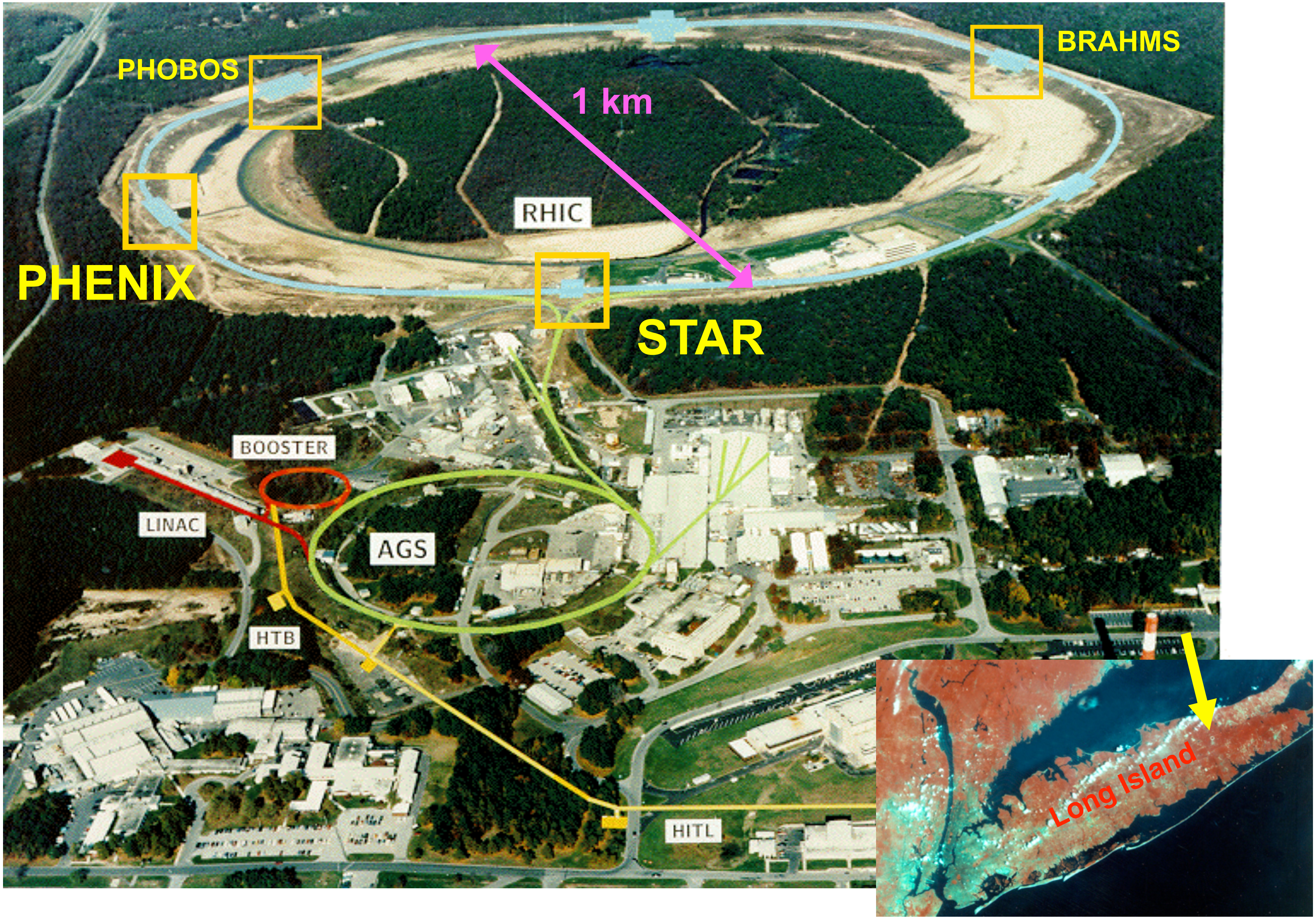
MEIC:
- 3-11 GeV e
- 60 GeV p ($\sqrt{s}$ = 51 GeV)
- 24 GeV/n ion ($\sqrt{s}$ = 33 GeV)
- L~ $1 \cdot 10^{34}$ cm^{-2} s^{-1} @ 5+60 GeV
- L~ 10^{33} cm^{-2} s^{-1} otherwise
- Up to heavy ion A = 208

ELIC: upgrades
- 250 GeV p ($\sqrt{s}$ = 105 GeV)
- 100 GeV ion ($\sqrt{s}$ = 66 GeV)
- L up to 10^{35} cm^{-2} s^{-1}

ELIC: upgrades
- Increase E_e



EIC Concept: RHIC → eRHIC @ BNL



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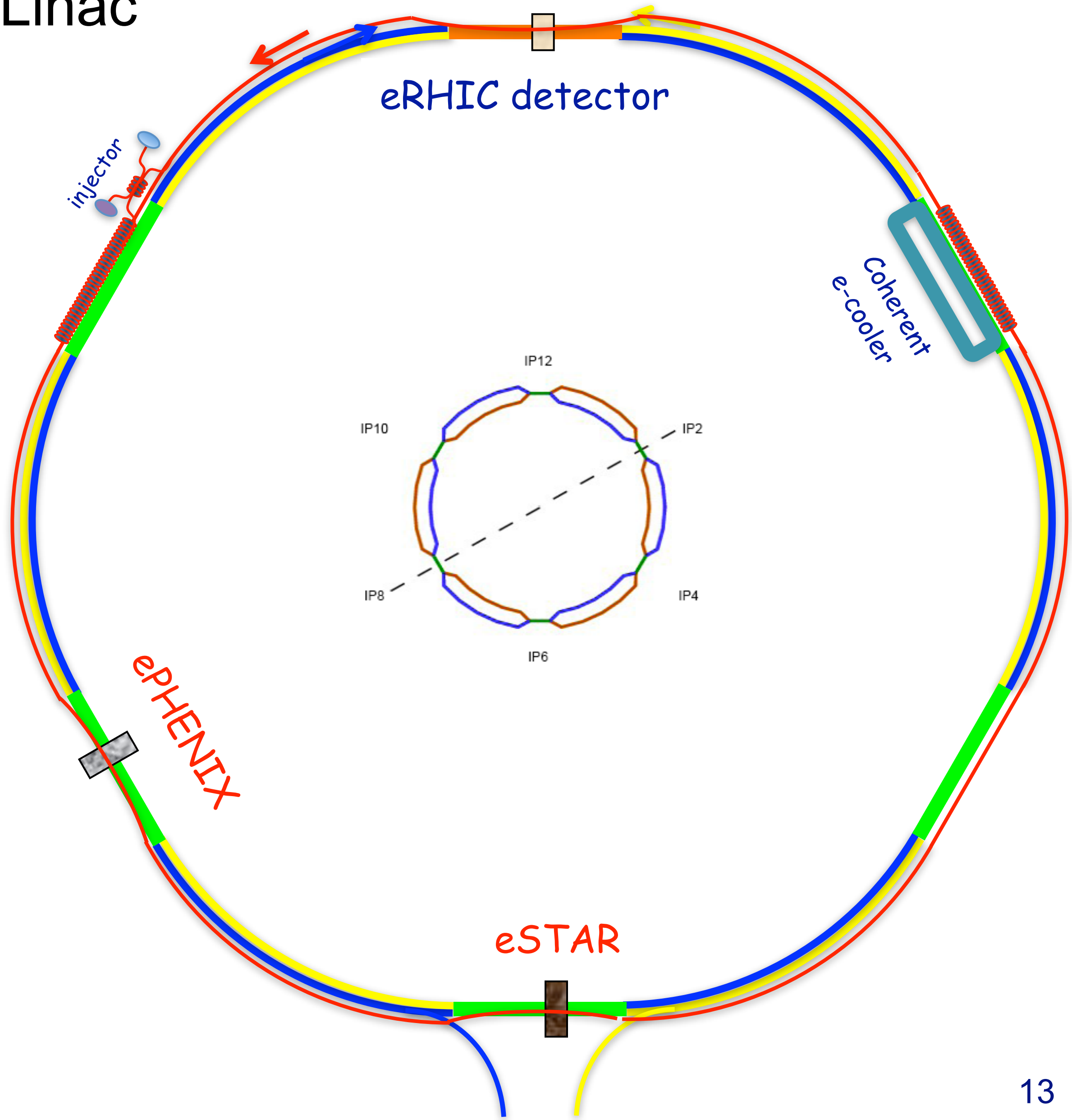
ERL: Energy Recovery Linac
1 - 5 GeV per pass
4 (6) passes



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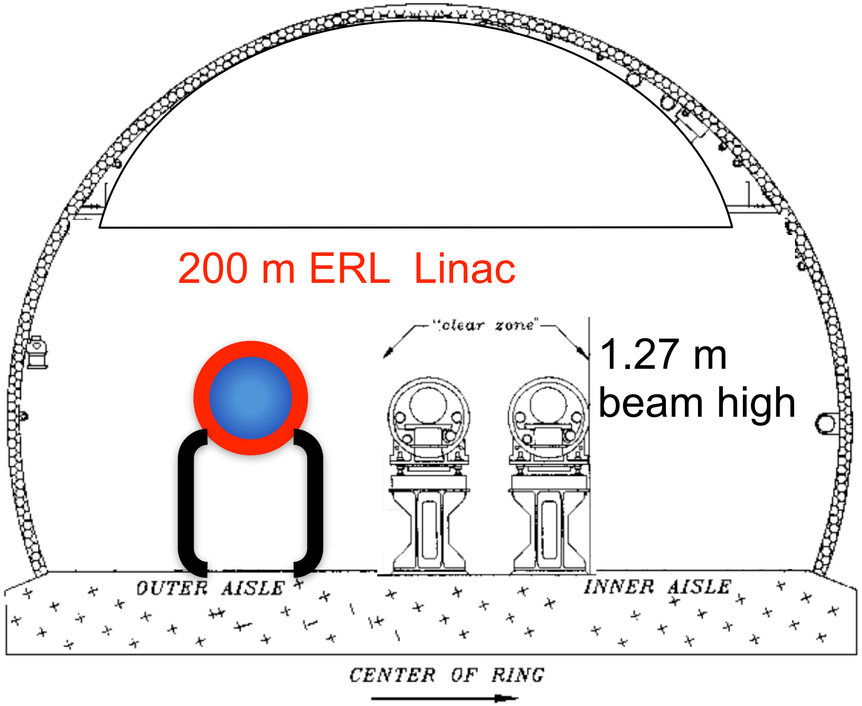

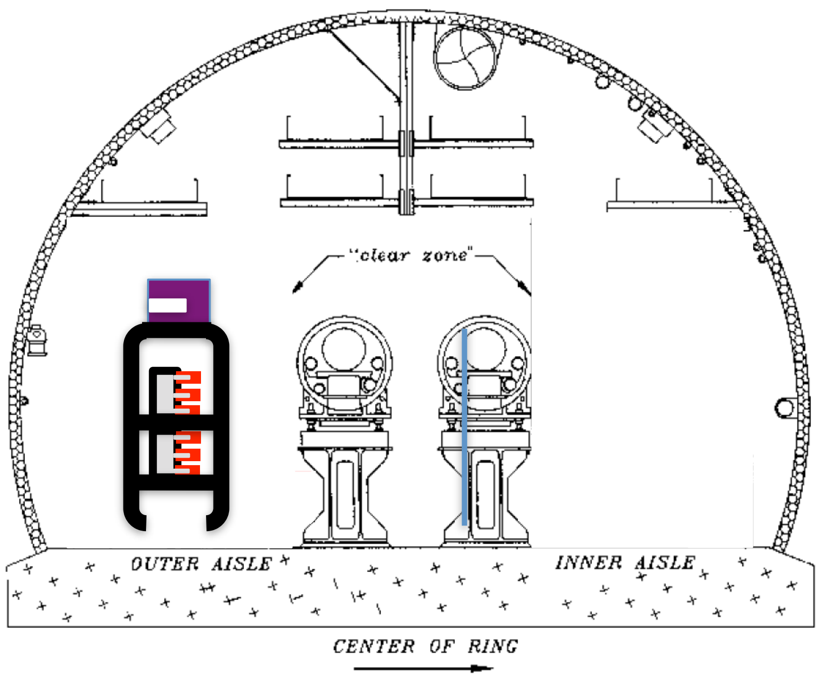

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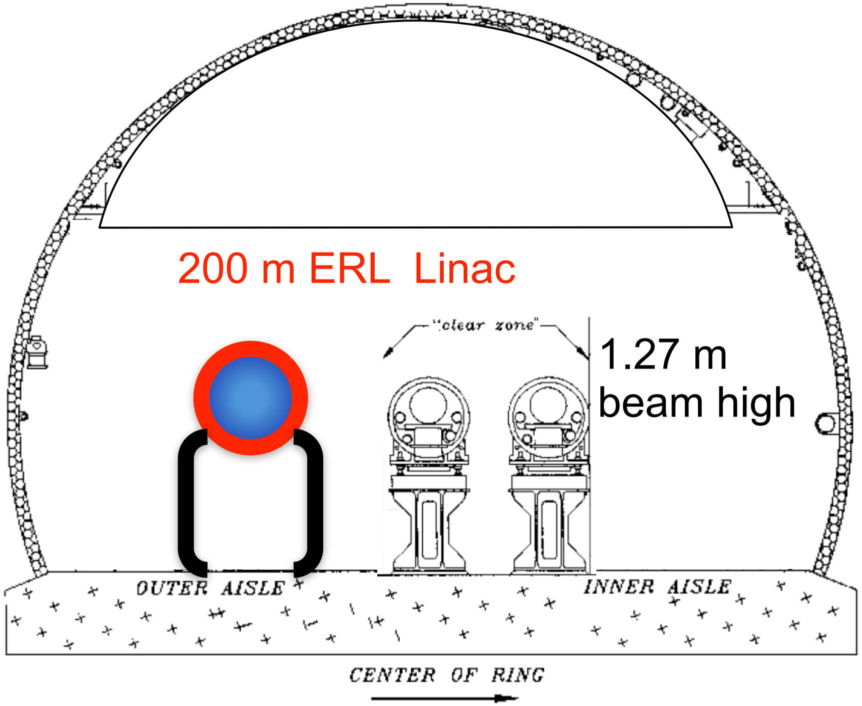
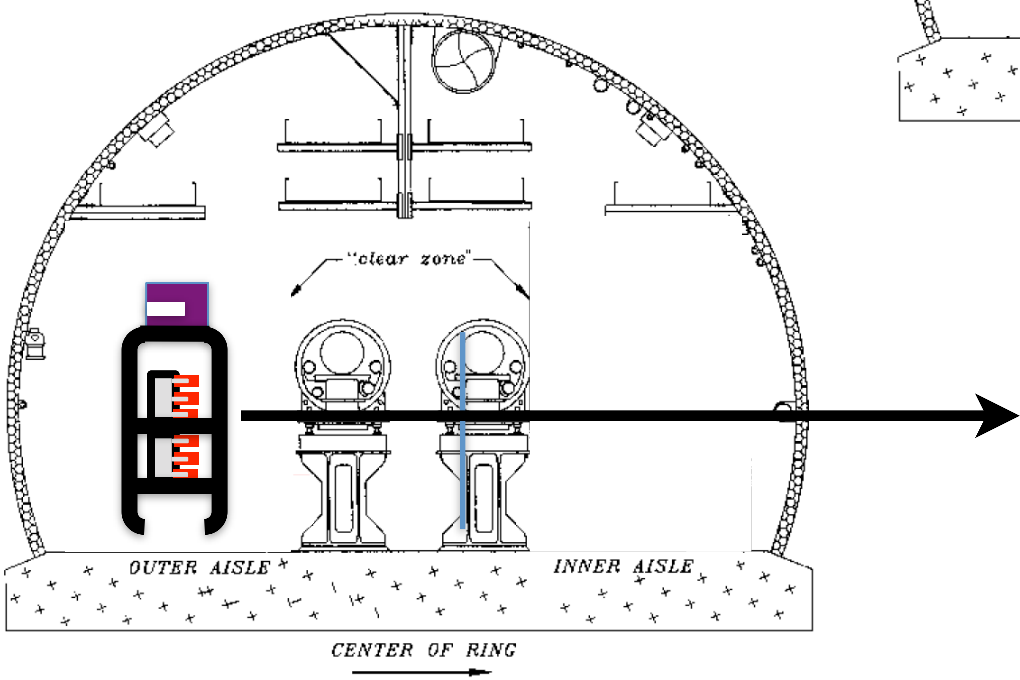
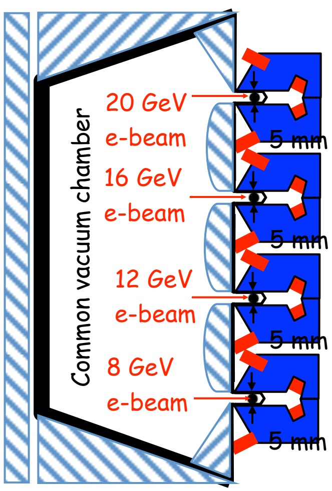






EIC Concept: RHIC → eRHIC @ BNL

eRHIC (stage 1):

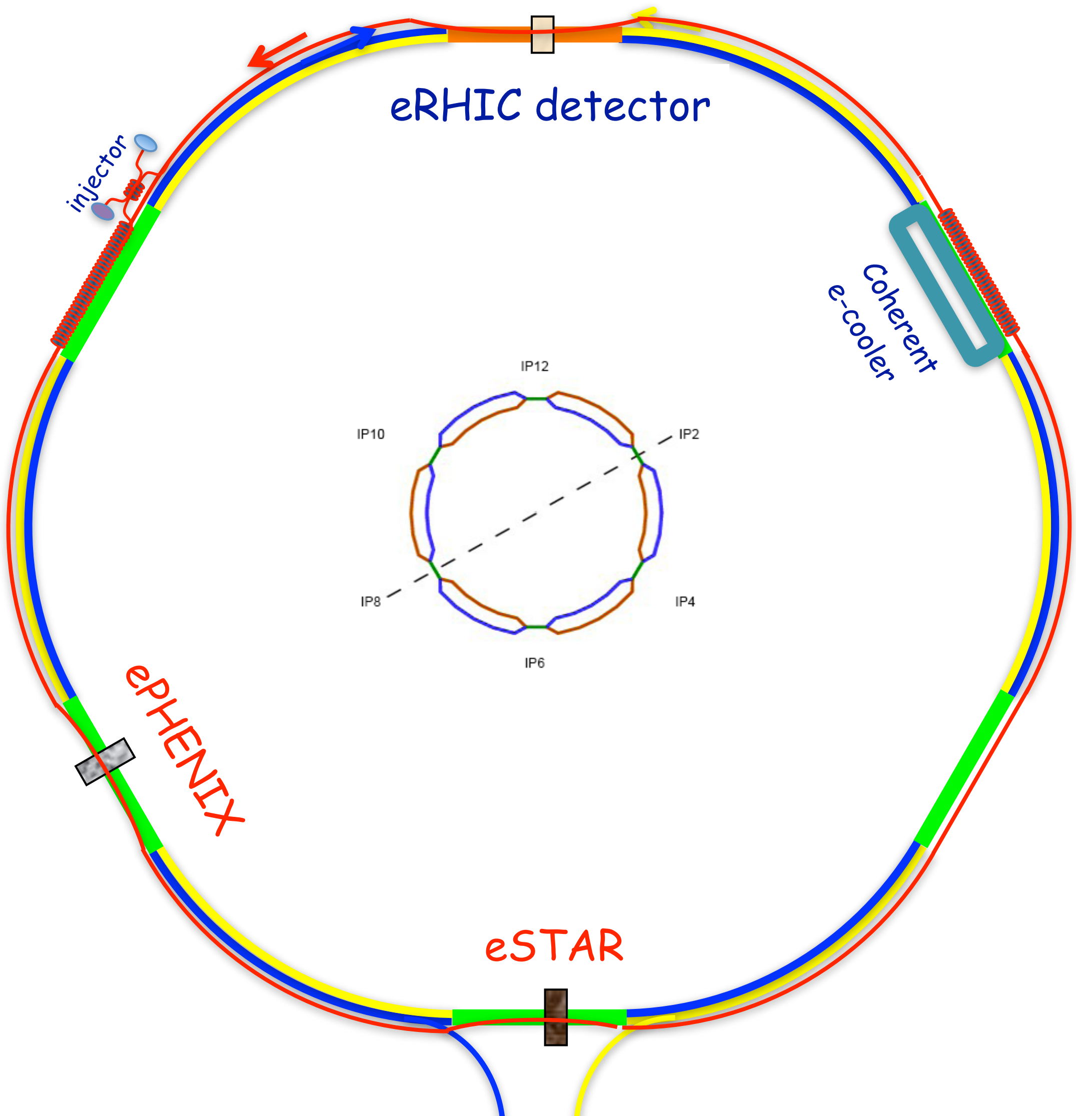
- 4 GeV e x 250 GeV p ($\sqrt{s}$ = 63 GeV)
- 4 GeV e- x 100 GeV/n Au ($\sqrt{s}$ = 40 GeV)
- L ~ 10^{32}-10^{33} cm^{-2} s^{-1}

eRHIC (stage 2):

- 20 GeV e x 325 GeV p ($\sqrt{s}$ = 160 GeV)
- 20 GeV e x 130 GeV/n Au ($\sqrt{s}$ = 102 GeV)
- L ~ $1.4\cdot10^{34}$ cm^{-2} s^{-1}

eRHIC upgrades

– Higher luminosity
– Higher hadron energy

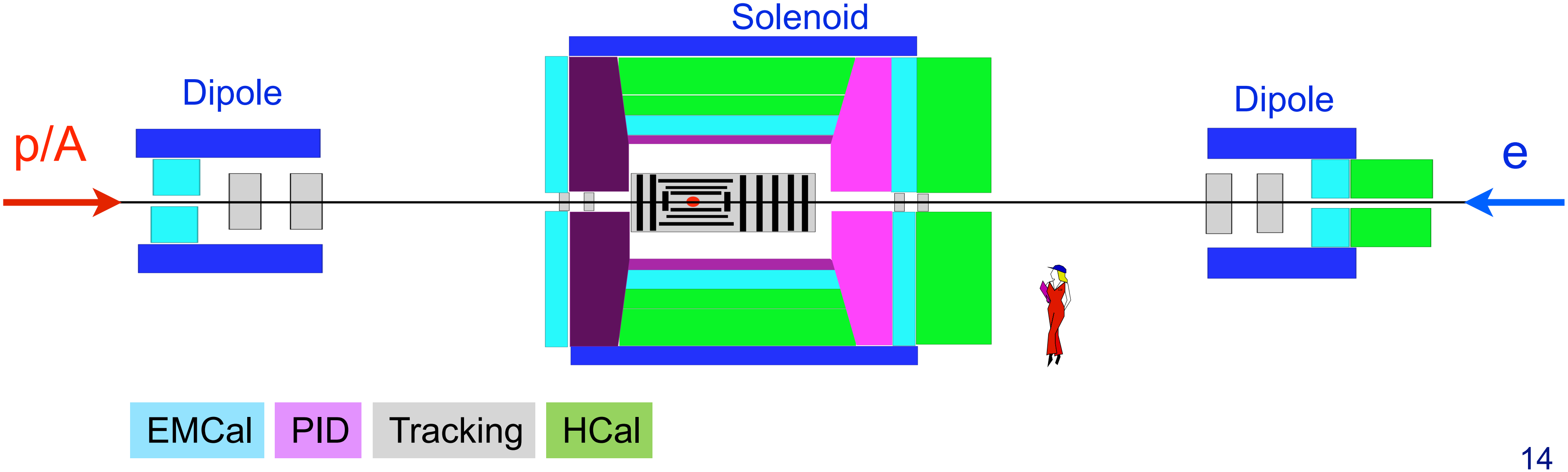


eRHIC: Detector ⇔ IR Design

Detector:

- Hermeticity (diffraction ⇔ rapidity gap)
- Extreme forward angle ⇔ low-x physics
- PID < 4 GeV/c in central detector
- PID up to 100 GeV for forward rapidities
- High precision for scattered electron that defines event kinematics (Q^2, x, ...) ⇒ low material

Detector concept (schematic):

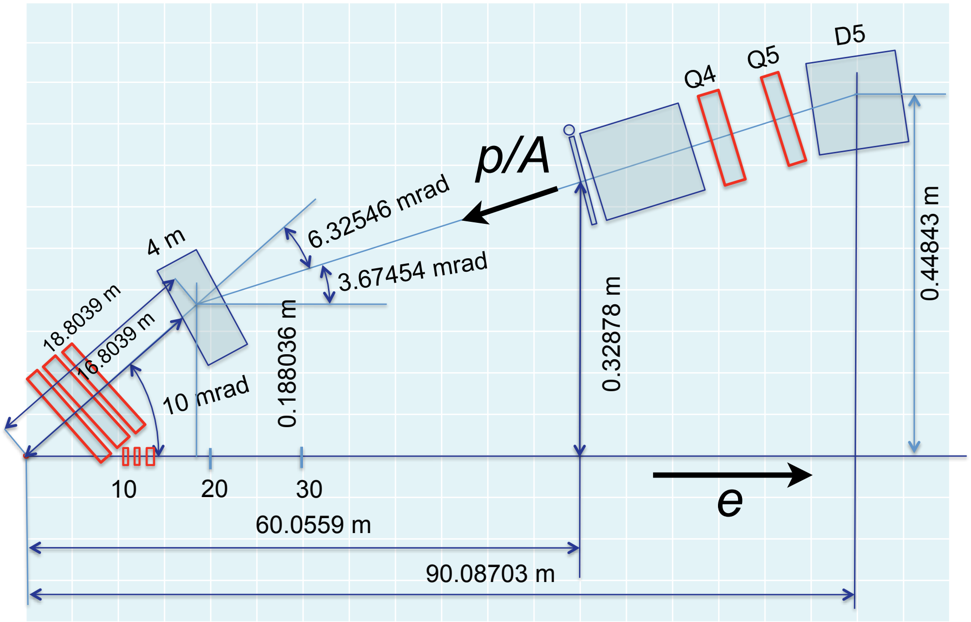


eRHIC: Detector ⇔ IR Design

IR:

- minimize synchrotron radiation (P and λ)
- minimize $\beta^* \Rightarrow L$
- First quads: maximize aperture for particles at extreme forward angle $\Rightarrow$ detect n from breakup (diffraction)
- Design depends on presence/absence of pp/pA/AA ops

High Luminosity IR (β^* = 5 cm)



Dejan Trbojevic

Latest Design:

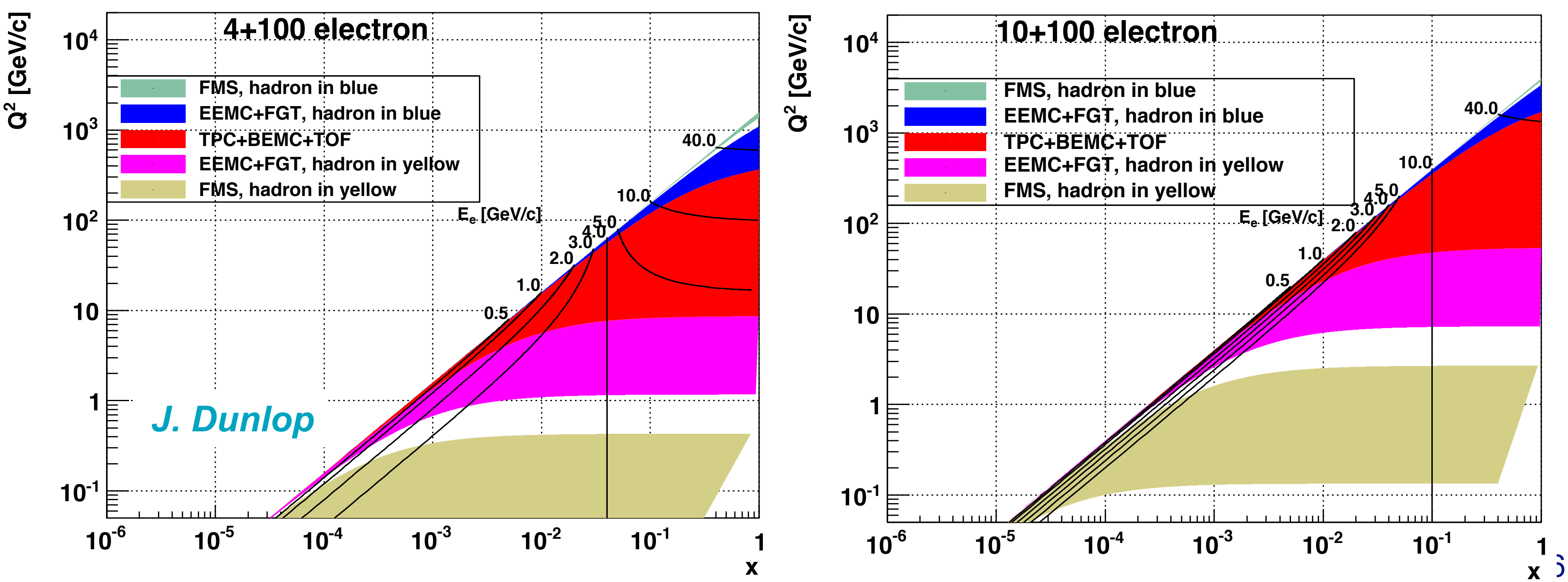
- ep(A) crossing angle of 10 mrad
- straight e beamline
  $\Rightarrow$ no synchrotron radiation
- good separation of e/p beamlines
  - real estate for additional detectors
- need to fine tune for optimal instrumentation
- aperture of 1st quad: ±5 mrad
  - important for breakup-neutron detection

Heavy Ion Experiments and ep/eA?

eRHIC & staged eRHIC:

- Electron beam around RHIC tunnel
- Requires scheme for getting electron beamline through or around PHENIX and STAR
- Can STAR/PHENIX make use of the e-p and e-A collisions?
  - RHIC decadal planing: experiments are looking into it

Example: STAR



EIC Outlook

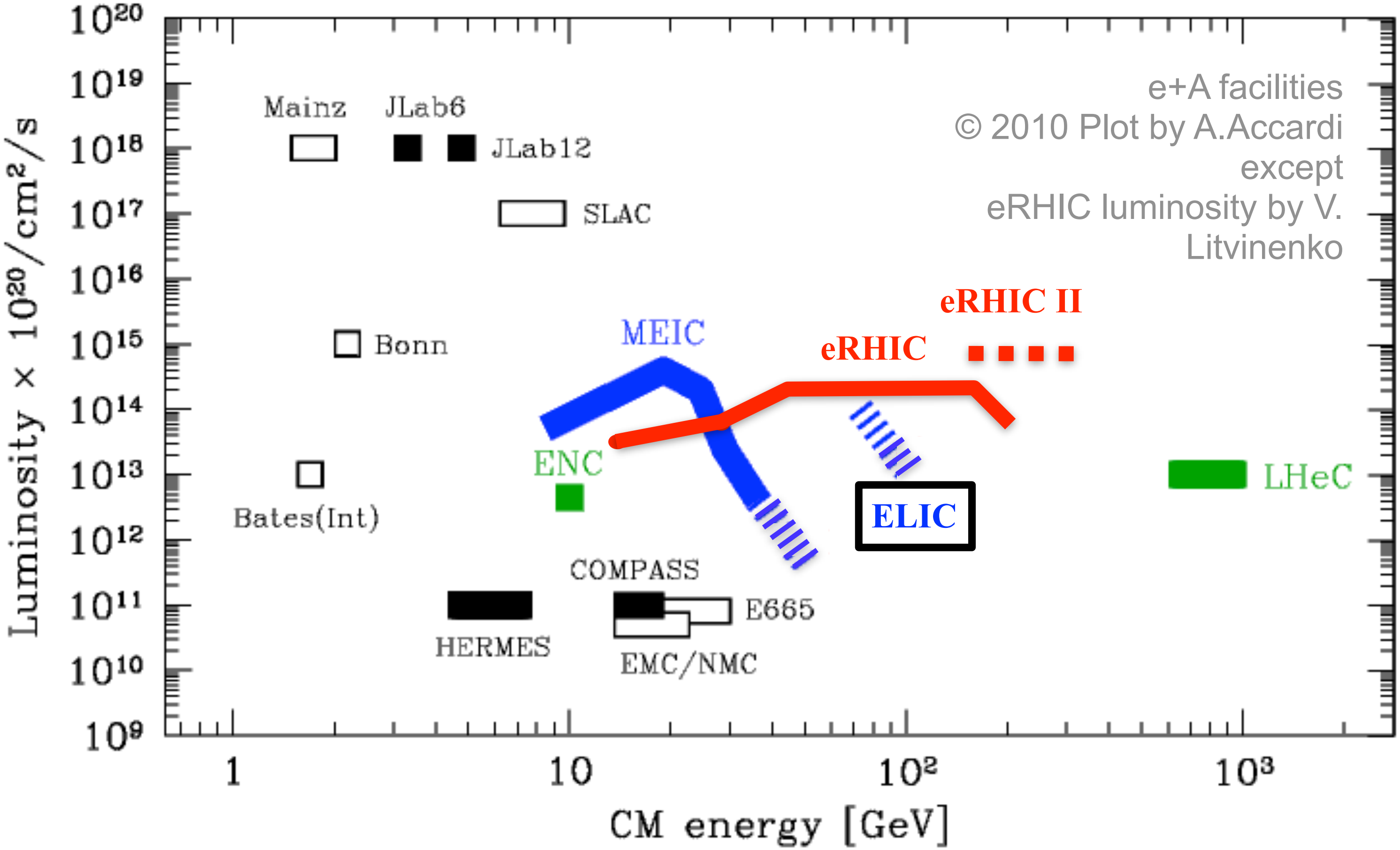
- Increasing efforts at BNL & JLAB
- Concepts of eRHIC and ELIC are taking shape
  - Substantial progress in machine & IR design
- Staged approach most promising path
  - Much can be done already at lower energy (e.g. F_L)
  - Saturation physics will require full ELIC/eRHIC
- At minimum one large multi-purpose detector
- ePHENIX/eSTAR under evaluation

Key Events:

- INT Workshop: Gluons and the Quark Sea at High Energies: Sep-Nov, 2010 $\Rightarrow$ Science Case for EIC
- LRP 2012: Town meetings and LRP

Additional Slides

Past and Future Electron-Hadron Collider



Very long term future

- LHeC: add linac/ring to existing LHC
  - 70 GeV e-beam on 2.8 TeV Pb (7 TeV p), $\sqrt{s_{eN}}$ = 885 GeV
- ENC@FAIR: add e-ring to planned HESR p ring
  - 3.3 GeV e-beam on 15 GeV p, $\sqrt{s}$ = 14 GeV

Measurements & Techniques

- Gluon Distribution $G(x,Q^2)$
  - Scaling violation in F_2: $\delta F_2/\delta \ln Q^2$
  - $F_L \sim xG(x,Q^2)$
  - 2+1 jet rates
  - Diffractive vector meson production ($[xG(x,Q^2)]^2$)
- Space-Time Distribution
  - Exclusive diffractive VM production (J/ψ, ϕ, ρ)
  - Deep Virtual Compton Scattering (nGPDs)
  - Structure functions for various mass numbers A and its impact parameter dependence